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ORIGINAL ARTICLE

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Spreading the sparing: against a limited-capacity account of the attentional blink

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Abstract The identification of the second of two targets presented in close succession is often impaired—a phenomenon referred to as the attentional blink. Extending earlier work (Di Lollo, Kawahara, Ghorashi, and Enns, in Psychological Research 69:191–200, 2005), the present study shows that increasing the number of targets in the stream can lead to remarkable improvements as long as there are no intervening distractors. In addition, items may even recover from an already induced blink whenever they are preceded by another target. It is shown that limited memory resources contribute to overall performance, but independent of the attentional blink. The findings argue against a limited-capacity account of the blink and suggest a strong role for attentional control processes that may be overzealously applied.

Introduction

The human visual system appears limited in the amount of information it can process across time, as has become apparent from the rapid serial visual presentation (RSVP) paradigm, in which stimuli (typically alphanumerical characters) are shown in rapid succession to the observer. It is often found that the detection of the second of two targets (T2) within such a stimulus stream is impaired when presented within about 500 ms after the first target (T1, e.g., Chun and Potter, 1995; Raymond, Shapiro, and Arnell, 1992; see also Kahneman, Beatty, & Pollack, 1967). To characterize this phenomenon, Raymond et al. (1992) proposed the term attentional blink: it is as if attention is temporarily unavailable for new input when processing earlier relevant visual information.

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One of the characteristics of the attentional blink is that it often does not occur for a second target when this target immediately follows the first target, i.e., at lag 1. This phenomenon is referred to as “lag-1 sparing” and it appears to occur as long as the transition from T1 to T2 does not involve a task switch or a location shift (Potter, Chun, Banks, & Muckenhoupt, 1998; Visser, Zuvic, Bischof, & Di Lollo, 1999b).

Prevalent explanations of the attentional blink and lag-1 sparing stress limited-capacity resources as their major cause. For instance, according to the bottleneck account, T1 needs to be consolidated in short-term memory (STM) for it to be available for conscious report (Chun & Potter, 1995; Jolicoeur & Dell’Acqua, 1998). This process of consolidation requires limited-capacity resources, which are then unavailable (or at least not sufficiently available) for T2, whose representation therefore remains vulnerable and becomes easily overwritten by the subsequent items in the stream (which are believed to act like masks, Brehaut, Enns, & diLollo, 1999; Dell’Acqua, 2003; Giesbrecht & DiLollo, 1998; Grandison, Ghirardelli, & Egeth, 1997; Seiffert & DiLollo, 1997). Lag-1 sparing may then be explained by assuming that when T1 and T2 occur in close succession, the exact temporal order information is often lost, and both targets may compete more or less equally for the same resources (Potter, Staub, & O’Conner, 2002). The interference account of Shapiro and Raymond and colleagues (Raymond, Shapiro, & Arnell, 1995; Shapiro & Raymond, 1994; Shapiro, Raymond, & Arnell, 1994) poses that rather than just a single item, multiple items may enter a STM stage. Typically this would involve the two targets, but also some of the intervening or subsequent distractor items. Within STM these items then compete for report. This competition is heavily biased by a number of factors, one of them being the order of entrance into STM. More attentional resources are assigned to T1 (by virtue of it being the first target) and often its immediate successor (because it so closely follows T1). This also explains the lag-1 sparing phenomenon. However, because the total attentional weight within STM is limited, the assignment of resources to these early items will be automatically at the expense of the somewhat later items, including T2, which may even fail to enter STM at all if resources are insufficient. Thus, even though multiple items are in theory allowed to enter the limited-capacity stage, the overall principle is the same as in the bottleneck theory: capacity is limited, and it is used up by T1.

First indications against a limited-capacity account

A number of recent findings argue against a T1-induced resource deficiency as a sufficient or even necessary explanation of the attentional blink. Olivers and Nieuwenhuis (2005a, b) have shown that the attentional blink is attenuated when observers adopt a more distributed attentional state, which may be induced by, for example, an additional cognitive task or by positive affect (Ashby, Isen, & Turken, 1999; Derryberry & Tucker, 1994). Performance for T2 improved when participants were instructed to concentrate less, simultaneously think of their holidays, listen to music, perform an additional memory task or watch positively laden emotional pictures. I. Arend, S. Johnston and K. Shapiro (unpublished results, as cited in Kessler et al., 2005) found improvements when the RSVP stream was embedded in a distracting visual display of random "starfield" motion. One may argue that these manipulations simply led to a redistribution of resources away from T1 and towards T2. Against this, however, Olivers and Nieuwenhuis found that T1 detection too improved under distracting conditions. To explain these findings, Olivers and Nieuwenhuis (2005b) proposed that the attentional blink is due to an overinvestment of attention in the RSVP stream rather than due to a lack of attentional resources. We will return to how this may work in the General discussion.

Findings by Di Lollo, Kawahara, Ghorashi, and Enns (2005; Kawahara, Enns, & Di Lollo, 2005) also argue against an explanation in terms of a T1-induced resource deficiency. Their study focused on triplets of items that were embedded in an RSVP stream of distractors. In one condition, the triplets consisted of a target, a distractor and a second target (i.e. T1 D T2). As expected, relative to T1, performance dropped substantially for T2, indicative of an attentional blink. In another condition, the triplets consisted of three successive targets (i.e. T1 T2 T3). Note that in this three-target condition, the last target (now T3) was in exactly the same temporal position relative to T1 as was the last target (T2) in the two-target condition. If the attentional blink is caused by a T1-induced resource deficiency, an attentional blink would again be expected for this last target, especially because the additional target in between is assumed to also require resources. However, Di Lollo et al. (2005) found that detection accuracy for T3 in the three-target triplets did not differ from that for T1. In other words, there was no attentional blink, but "lag-2 sparing" instead. They further found that performance for the middle target was best of all. Di Lollo et al. (2005) argued that, in principle, there are sufficient resources available to process multiple targets in close succession (at least more than one or two). They proposed that instead, the attentional blink is caused by a temporary disruption of endogenous attentional control settings. According to this temporary loss of control (TLC) account, observers seek to filter the information in the RSVP stream by setting up an attentional set that matches the target category (e.g., letters) and rejects the distractor category (e.g., digits). The maintenance of such an attentional set demands a certain amount of executive control. However, when T1 is presented, these same executive control functions are needed to process the target. The consequence is a TLC over the input filter. This loss of control is harmless as long as the incoming items are targets, but it becomes harmful when it allows for distractors to enter. According to the TLC account, a distractor will exogenously disrupt the now vulnerable input settings, affecting the selection of subsequent items. Given sufficient time, attentional control will be regained and the input filter will be reinstated. Thus, according to the TLC account, the attentional blink is not due to limited resources at the level of the individual targets. Instead, the limitations lie at a higher, executive level where only one task aspect (target identification, input control) can be actively handled at a time.

The present study

The present study sought to further investigate the roles of limited capacity and attentional control settings in the attentional blink, as well as the relationship between them. For this purpose we used RSVP streams containing up to four targets. Targets could be presented in immediate succession or with distractors inserted at various temporal positions (lags). According to the T1-induced resource deficiency accounts, the occurrence of the attentional blink should be tied to T1, regardless of following targets. If anything, additional targets are expected to aggravate the blink, since additional resources are required. According to the TLC account, T1 processing destabilizes the attentional input filter, allowing for distractors to disrupt it. This means that the attentional blink is not tied to T1, but to the occurrence of the first post-T1 distractor. As long as no such distractor is presented, the processing of additional targets should be unaffected.

Experiment 1 replicated and extended Di Lollo et al.'s (2005; see also Kawahara et al., 2005) work: sparing from the attentional blink is not limited to lag 1, but can be extended to lag 2 and even lag 3 as long as the intervening items are targets too. Performance for the fourth target was nevertheless affected, suggesting a remaining role for capacity limitations. Experiment 2 repeated the main manipulations, but controlled for differential masking effects between targets and distractors. Again sparing was found for T3 and T4. A new and exciting finding was that once a proper attentional blink had been induced (through an intervening distractor), subsequent targets could recover from this blink when preceded by another target. This indicates that control processes were still in place, responding dynamically to the changing input. Furthermore, the data suggested that multiple initial targets may induce a more profound blink for later targets than may just a single initial target, again pointing towards a residual role for capacity limitations. Experiment 3 served to explore both these effects further. It showed that across its entire time course, target items may escape from the attentional blink. Furthermore, multiple items did eventually induce a greater drop in performance, but this effect was additive with the effect of temporal position (lag). This indicates that limited target processing capacity and the attentional blink independently contribute to performance; the one is not caused by the other.

Experiment 1: sparing spreads to lag 2 and lag 3

Di Lollo et al. (2005; Kawahara et al., 2005) have shown that sparing from the blink is not limited to lag 1, but may spread to lag 2 as long as the intervening item is a target too. They concluded that the attentional blink is not due to a lack of limited-capacity resources. The question is if there remains no role for limited-capacity target processing resources whatsoever. The mainstream theories of the attentional blink assume that the conscious report of the targets in the RSVP stream requires some sort of (visual) STM (e.g., Chun & Potter, 1995; Jolicoeur & Dell'Acqua, 1998; Raymond et al., 1995). Others have suggested that the capacity of STM is functionally limited to about three to four items (see Cowan, 2000, for an extensive review). This would mean that limited-capacity resources may still play a role in the attentional blink if we tax STM a little further. Using stimuli that were highly similar to those used by Di Lollo et al. (2005), we presented quadruplets of items embedded in a stream of distractors. Table 1 shows the different possible sequences of targets and distractors. In the one-target (1-T) control condition, a single target was presented at any of the four positions within the quadruplet, while the rest was filled with distractors. In the two-target (2-T) standard attentional blink condition, T1 was presented on the first position, whereas T2 could follow on any of the remaining three positions (i.e. at lag 1, 2, or 3; again the rest was filled with distractors). An attentional blink was expected for T2. In the three-target (3-T) condition, T1 was presented on the first position, whereas the remaining three positions were filled with the various possible combinations of T2, T3 and a distractor. Finally, in the four-target (4-T) condition, the four positions were successively filled with T1, T2, T3 and T4. On the basis of the TLC account we expected sparing in the 4-T condition to spread to T4. However, if available STM capacity contributes to performance, we may expect a performance drop for the final T4 target (compared to the 3-T and 2-T conditions), since most of the resources have been used up by the first three targets.

Further support for a limited-capacity account may come from comparing the 3-T condition to the 2-T condition. Notably, detection of the final target (T3) in the T1 T2 D T3 quadruplet (where "D" denotes a distractor) is expected to be worse than that of the final target (T2) in the T1 D D T2 quadruplet, because the initial two targets require more resources than an initial single target.

Finally, for exploratory purposes, we also included the T1 D T2 T3 quadruplet. Both the resource deficiency and TLC account predict the occurrence of an attentional blink for T2 here. But what will happen for T3? The resource deficiency account predicts a clear blink for this target too. However, the TLC account is less clear in its predictions. It states that the presentation of a distractor exogenously disrupts the input filter. But what does the presentation of a target do to the filter? A proper loss of control would suggest that the filter stays disrupted and we would therefore also expect an attentional blink for T3. However, if the control processes are more dynamic, and a proper input filter can be reinstated on presentation of a target (in this case T2), we might expect T3 to be spared.

As in Di Lollo et al.'s study (2005), participants were not required to report the targets in the order of presentation. Moreover, although targets were randomly chosen from a set, there was the restriction that all targets within a stream had to be different; thus, probabilities of occurrence were not independent. This meant that we felt the need to take into account the possibility of guessing—something Di Lollo et al. (2005) did not do. This is because the more targets are reported, the higher the chance that one gets at least one of them right merely by guessing. Note further that from hereon we will avoid the term "lag" as much as possible and use the term "temporal position" instead. This is because "lag" is defined relative to T1, whereas we were interested in effects of targets beyond T1.

Method

Participants

Twelve students of the Vrije Universiteit Amsterdam (nine males; two left-handed; aged 17–33 years; average 22 years) participated in return for monetary payment.

Stimuli, procedure and design

Stimulus generation and response recording were done using E-Prime (Psychology Software Tools, Inc.,

Table 1 Possible target–distractor sequences for the one-target (1-T), two-target (2-T), three-target (3-T) and four-target (4-T) conditions of Experiments 1 and 2, and the predictions according to the resource deficiency and TLC accounts

Condition	Possible sequences	Predictions	
		Resource deficiency	TLC
1-T	T1 D D D	n/a	n/a
	D T1 D D	n/a	n/a
	D D T1 D	n/a	n/a
	D D D T1	n/a	n/a
2-T	T1 T2 D D	No blink for T2	No blink for T2
	T1 D T2 D	Blink for T2	Blink for T2
	T1 D D T2	Blink for T2	Blink for T2
3-T	T1 T2 T3 D	No blink for T2; blink for T3	No blink for T2 or T3
	T1 T2 D T3	No blink for T2; blink for T3	No blink for T2; blink for T3
	T1 D T2 T3	Blink for T2 and T3	Blink for T2; for T3 unclear
4-T	T1 T2 T3 T4	No blink for T2; blink for T3 and T4	No blink for any

Note the quadruplets were embedded in a stream of distractors

Pittsburgh, PA, USA). After a 1,000-ms blank period, a 0.5°×0.5° fixation cross was presented for 1,000 ms in the center of the display, and subsequently replaced by a rapid serial presentation of 19–22 letters, each measuring approximately 0.8×0.8°. The entire RSVP series (including the fixation cross) was presented in black on a gray (40 cd/m^2) background. Each letter was randomly drawn (without replacement) from the alphabet and presented for 75 ms, followed by a 25 ms blank. "I", "O", "Q" and "S" were left out as they may resemble digits too much. On each trial, one to four letters were replaced with digits, randomly drawn (without replacement) from the set 0 to 9. The first target (T1) was presented randomly between positions 12 and 16 inclusive. Subsequent targets, when present, followed within the next three positions, which were otherwise filled with distractors. This way, the relevant items were all presented as a quadruplet embedded in a stream of distractors. The participant's task was to identify all targets and an unspeeded response was made at the end of each trial by typing in the digits on a standard keyboard. Participants were instructed to guess whenever they failed to identify a digit. They were also asked to enter the targets in the order they perceived them, if possible, but it was made clear that this was not crucial. Correctly identified targets that were entered in the wrong order were counted as correct. Feedback on accuracy was given after each trial.

Table 1 summarizes all possible target–distractor sequences within the relevant quadruplets. In the 1-T control condition, a single target was presented in any of the four possible temporal positions (with equal probability). In the 2-T condition, T1 was presented on the first position, and T2 could then appear at positions 2, 3 or 4. In the 3-T condition, T1 was presented on position 1, T2 could appear on either of positions 2 and 3, whereas T3 could appear on either of positions 3 and 4 (depending on T2; see Table 1). In the 4-T condition, T1, T2, T3 and T4 appeared at positions 1, 2, 3 and 4, respectively.

The experiment started with 12 practice trials for each number of targets, followed by two sessions of four blocks each, with a short break in between. Within each session, there was one block for each number of targets, and block order was randomized. Temporal positions of the target(s) were randomly varied within a block. Each block contained 36 trials. The experiment lasted approximately 45 min.

Results

Proportions correct for each target were first corrected for guessing depending on the number of targets in the condition. In the 1-T condition, we assumed that the observed proportion correct ($P_{\mathrm{T1\_obs}}$) consisted of a proportion really perceived targets ($P_{\mathrm{T1\_real}}$) plus a proportion guessed targets ($P_{\mathrm{T1\_guess}}$). Since we used ten digits as possible targets, the latter component can be described as $P_{\mathrm{T1\_guess}} = (1 - P_{\mathrm{T1\_real}})\frac{1}{10}$, so that:

$$P_{\mathrm{T1\_obs}} = P_{\mathrm{T1\_real}} + (1 - P_{\mathrm{T1\_real}})\frac{1}{10}. \tag{1}$$

In the 2-T condition, observed performance for T1 ($P_{\mathrm{T1\_obs}}$) depended not only on whether T1 was perceived ($P_{\mathrm{T1\_real}}$) or guessed ($P_{\mathrm{T1\_guess}}$) correctly, but also if T2 was perceived ($P_{\mathrm{T2\_real}}$) correctly. This is because if neither T1 nor T2 was perceived correctly, there were two chances of guessing T1 correctly (since order of report did not matter). The same goes for T2, leading to the following set of equations:

$$\begin{aligned} P_{\mathrm{T1\_obs}} = {} & P_{\mathrm{T1\_real}} \\ & + (1 - P_{\mathrm{T1\_real}})(1 - P_{\mathrm{T2\_real}})\frac{2}{10} \\ & + P_{\mathrm{T2\_real}}(1 - P_{\mathrm{T1\_real}})\frac{1}{9}, \end{aligned} \tag{2}$$

$$\begin{aligned} P_{\mathrm{T2\_obs}} = {} & P_{\mathrm{T2\_real}} \\ & + (1 - P_{\mathrm{T1\_real}})(1 - P_{\mathrm{T2\_real}})\frac{2}{10} \\ & + P_{\mathrm{T1\_real}}(1 - P_{\mathrm{T2\_real}})\frac{1}{9}. \end{aligned} \tag{3}$$

The same principle was applied to the 3-T and 4-T conditions, resulting in equivalent but increasingly complex equations. These equations were then numerically solved for $P_{\mathrm{T1\_real}}$, $P_{\mathrm{T2\_real}}$, $P_{\mathrm{T3\_real}}$ and $P_{\mathrm{T4\_real}}$.

Figure 1 shows these real proportions correct target identification for the different numbers of targets after correction for guessing, as a function of temporal position. In the multiple target conditions (i.e. 2-T, 3-T and 4-T), accuracy for the post-T1 targets was contingent upon correct T1 identification. It deserves mentioning though that the same pattern of results held when analyzed independently of T1 accuracy. Figure 1 reveals a complex pattern of findings and we will discuss them step by step. A mnemonic may be of help in interpreting Fig. 1: the single line "_" symbol represents the single target (1-T) condition; the "X" (containing two lines) represents the 2-T condition; the triangle (three sides) represents the 2-T condition; and the square (four sides) represents the 4-T condition (see also the figure caption). Note further that not all conditions contained targets in all temporal positions, so an omnibus ANOVA was not possible. Therefore, separate comparisons were performed where appropriate.

In the 1-T control condition, overall accuracy was high (91%) and there was no effect of temporal position (1–4; $F < 1$, $P > 0.5$), indicating that the position within the RSVP stream per se did not contribute to performance. The pattern in the 2-T condition was different from that in the 1-T condition, as indicated by a number of targets (1-T vs. 2-T) × temporal position (1–4) interaction, $F(3, 33) = 27.07$, $\mathrm{MSe} = 0.009$, $P < 0.001$. Accuracy was quite high for T1 (temporal position 1) and for T2, when it immediately followed T1 (temporal position 2), reflecting the lag-1 sparing effect. In contrast, performance showed a steep drop relative to the single target control condition, when T2 was presented at temporal positions 3 and 4, $t(11) = 6.71$, $P < 0.001$ and $t(11) = 6.39$, $P < 0.001$, respectively. Thus, the 2-T condition reveals a standard attentional blink pattern.

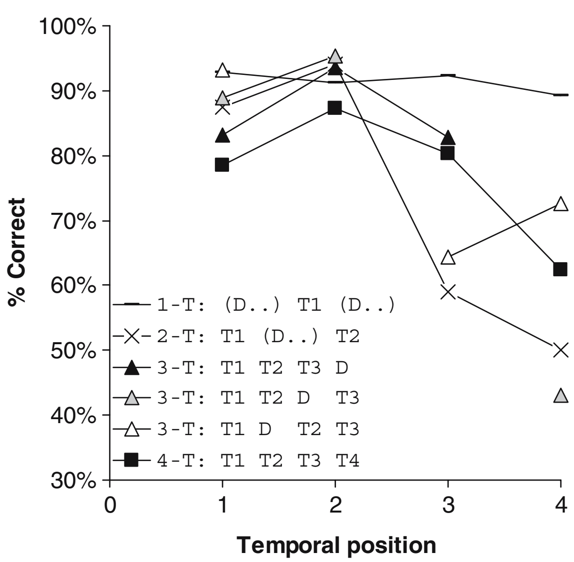

Fig. 1 Percentage correct scores for the single target (*1-T*), two target (*2-T*), three target (*3-T*) and four target (*4-T*) conditions of Experiment 1, as a function of temporal position. To aid interpretation of the data, the number of line segments or sides in the *symbols* represent the number of targets in that condition (i.e. "_" = 1-T; "*X*" = 2-T, "*triangle*" = 3-T and "*square*" = 4-T). Conditions differed in the various combinations of target (*T1–T4*) and distractor (*D*) quadruplets, with (*D*..) referring to a variable number of distractors (see Table 1 for all possible quadruplets)

We subsequently assessed if presenting more than two targets leads to deviations from this standard attentional blink pattern. In the version of the 3-T condition in which the three targets were presented in succession (i.e. the T1 T2 T3 D quadruplet), the pattern was indeed different from that in the 2-T condition, as confirmed by a number of targets (2-T vs. 3-T) × temporal position (1–3) interaction, $F(2, 22) = 14.56$, $\mathrm{MSe} = 0.008$, $P < 0.001$. Pair-wise comparisons revealed that accuracy on temporal position 3 was substantially improved in the 3-T condition (83%) relative to the 2-T condition (59%), $t(11) = 3.78$, $P < 0.01$. Similar improvements relative to the standard 2-T condition occurred in the 4-T condition (featuring the T1 T2 T3 T4 quadruplet); number of targets (2-T vs. 4-T) × temporal position (1 to 4), $F(3, 33) = 12.48$, $\mathrm{MSe} = 0.011$, $P < 0.001$. Pair-wise comparisons revealed that performance was worse on temporal position 1 in the 4-T relative to the 2-T condition, $t(11) = 2.85$, $P < 0.05$, but better on temporal positions 3 and 4, $t(11) = 3.63$, $P < 0.01$ and $t(11) = 2.36$, $P < 0.05$, respectively. Nevertheless, performance was somewhat deteriorated for the fourth target, relative to the first three targets in the 4-T condition, all ts≥3, all Ps < 0.05. Thus, sparing spreads to the third and, to a lesser extent, the fourth temporal position, when targets immediately succeed each other.

The pattern in the T1 D T2 T3 quadruplet of the 3-T condition also differed remarkably from the standard attentional blink found in the 2-T condition, as indicated by a number of targets (2-T vs. 3-T) × temporal position (1, 3, 4) interaction, $F(2, 22) = 3.64$, $\mathrm{MSe} = 0.016$, $P < 0.05$. Pair-wise comparisons showed that accuracy in the 3-T condition was somewhat improved for temporal position 1 (93 vs. 88% in the 2-T condition), $t(11) = 2.31$, $P < 0.05$, did not differ for temporal position 3, but then remarkably improved again for position 4 (73 vs. 50%), $t(11) = 3.13$, $P = 0.01$. Thus, although a clear attentional blink had been induced (as indicated by T2 performance), T3 somehow managed to escape from this blink.

Taken together, these results suggest that the attentional blink is not induced by T1, but by the first post-T1 distractor. This is because an attentional blink occurred for the final targets in the T1 D T2 D, the T1 D D T2 and the T1 T2 D T3 quadruplets (as well as for the middle target in the T1 D T2 T3 quadruplet), whereas it was absent or considerably reduced in the T1 T2 D D, T1 T2 T3 D and T1 T2 T3 T4 quadruplets. The finding of relative sparing of a third and fourth target, in combination with a distractor-induced blink, replicates and extends findings by Di Lolllo et al. (2005) and provides direct support for the TLC account. However, there may still be an additional role for limited-capacity resources in target processing. The finding that accuracy for a fourth target, though relatively spared, was not as good as for earlier targets or as in the single target control condition, suggests that observers were running out of resources. The involvement of limited-capacity resources may also be suggested by the finding that processing multiple targets eventually led to a slightly deeper blink than when only a single target needed to be processed. Performance for the final target in the T1 T2 D T3 quadruplet of the 3-T condition was worse than for the final target in the quadruplet of the 2-T condition T1 D D T2 (43 vs. 50%). Although there was a trend, this difference failed to reach significance, $t(11)=1.63$, $P=0.13$. However, the same pattern also appeared in Experiments 2 and 3, and we will return to it later.

The finding that a target can be recovered even when a full blink has been induced (in the T1 D T2 T3 quadruplet) is quite exciting. Apparently, even though T2 itself was often not detected, it could nevertheless reopen the attentional "gate" for the subsequent T3. This effect too will be further investigated in later experiments. It is worth pointing out here though that this beneficial effect for the second of two targets also occurred before a blink was even induced, namely between T1 (temporal position 1, on average 83% correct) and T2 (temporal position 2, on average 93% correct), $t(11)=6.38$, $P<0.001$. This suggests that, more generally, detection of targets in an RSVP stream may improve from immediate repetition of the target category.

Experiment 2: controlling for masking

The general finding of Experiment 1 was that performance was relatively good as long as the target was preceded by another target. Although this finding is consistent with the idea that a loss of control over the input filter is not harmful as long as only targets are presented (as proposed by the TLC account), it may also be explained in terms of forward masking. In Experiment 1 the targets were digits, whereas the distractors were letters. It is possible that digits mask digits less well than letters mask digits, for example, because fewer features are shared or because of different pixel densities (cf. Maki, Bussard, Lopez, & Digby, 2003). To control for this we changed the stimuli in Experiment 2, so that targets were now letters, and distractors were taken from a set of "fantasy" characters. The stimuli are illustrated in Fig. 2. Across the set, the fantasy characters shared exactly the same line segments as the letters, in exactly the same quantities. This way, low-level visual forward masking effects should be equal within and across target and distractor categories, in terms of line features as well as pixel densities, and thus cannot explain potential sparing effects.

Method

Participants

Twelve students of the Vrije Universiteit Amsterdam (five males; one left-handed; aged 18–36 years; average 23 years) participated in return for monetary payment.

Stimuli, procedure and design

The experiment was the same as Experiment 1, except for the following changes. The targets were now drawn from a set of 23 letters consisting of a particular combination of line segments within a virtual square and its diagonals (similar to the characters often used in LCD displays of electrical appliances). Distractors were now drawn from a set of 23 fantasy characters, which were created by re-shuffling the line segments of the letters to form unrecognizable figures that were still somewhat letter-like (e.g., within a character line segments had to be connected). All stimuli are shown in Fig. 2. Thus, overall, the two sets shared the same features and the same number of pixels. Because of increased task difficulty, the timing of the characters was changed. The letters were presented for 58 ms each, followed by an 83 ms blank.

Results

The results were analyzed exactly as in Experiment 1. Proportions correct for each target were first corrected for guessing depending on the number of targets in the condition. The same method of correction was applied except that the basic chance level was now 1/23 (since there were 23 different target letters) instead of the 1/10 used in Experiment 1. Figure 3 shows the real proportions correct target identification for the different numbers of targets after correction for guessing, as a function of temporal position. Overall, accuracy was lower than in Experiment 1, $F(1, 22)=14.31$, $MSe=0.132$, $P=0.001$, but the general pattern of results was largely the same.

In the 1-T control condition (average accuracy 72%), there was no effect of temporal position (1–4; $F<1$, $P>0.5$). The pattern in the 2-T condition was different from that in the 1-T condition, as indicated by a number of targets (1-T vs. 2-T) × temporal position (1–4) interaction, $F(3, 33)=28.17$, $MSe=0.009$, $P<0.001$. Accuracy was relatively high for T1 (temporal position 1) and for T2 when it immediately followed T1 (temporal position 2; reflecting the lag-1 sparing effect). In fact, performance for T2 immediately after T1 was even better than when only a single target had to be detected (in the 1-T control condition), $t(11)=2.67$, $P<0.05$, a point to which we will return below. In contrast, performance showed a steep drop relative to the single target control condition, when T2 was presented at temporal positions 3 and 4, $t(11)=4.00$, $P<0.01$ and $t(11)=5.63$, $P<0.001$,

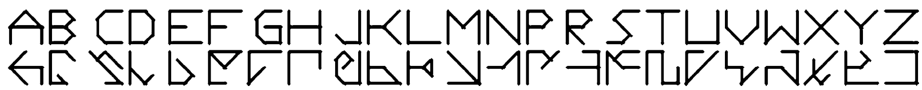

Fig. 2 The stimuli used in Experiments 2 and 3. The *top row* shows the target set, and the *bottom row* the distractor set

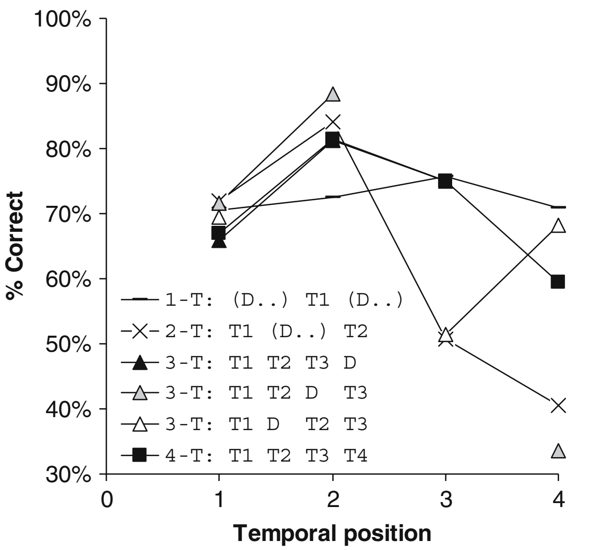

Fig. 3 Percentage correct scores for the single target (*1-T*), two target (*2-T*), three target (*3-T*) and four target (*4-T*) conditions of Experiment 2, as a function of temporal position. To aid interpretation of the data, the number of line segments or sides in the *symbols* represent the number of targets in that condition (i.e. "_" = 1-T; "*X*" = 2-T, "*triangle*" = 3-T and "*square*" = 4-T). Conditions differed in the various combinations of target (*T1–T4*) and distractor (*D*) quadruplets, with (*D*..) referring to a variable number of distractors (see Table 1 for all possible quadruplets)

respectively. Thus, the 2-T condition once more revealed a standard attentional blink pattern.

In the version of the 3-T condition in which the three targets were presented in a row (i.e. the T1 T2 T3 D quadruplet), the pattern was different from that in the 2-T condition, as confirmed by a number of targets (2-T vs. 3-T) × temporal position (1–3) interaction, $F(2, 22) = 13.84$, $MSe = 0.012$, $P < 0.001$. Pair-wise comparisons revealed that accuracy on temporal position 3 was substantially improved in the 3-T condition (83%) relative to the 2-T condition (59%), $t(11) = 3.45$, $P < 0.01$. Similar improvements relative to the standard 2-T condition occurred in the 4-T condition (featuring the T1 T2 T3 T4 quadruplet); number of targets (2-T vs. 4-T) × temporal position (1–4), $F(3, 33) = 12.11$, $MSe = 0.011$, $P < 0.001$. Pair-wise comparisons revealed that performance was slightly worse on temporal position 1 in the 4-T relative to the 2-T condition, $t(11) = 2.19$, $P = 0.051$, but better on temporal positions 3 and 4, $t(11) = 4.14$, $P < 0.01$ and $t(11) = 3.21$, $P < 0.01$, respectively. As in Experiment 1, sparing spread to the third and the fourth temporal position, when targets immediately succeeded one another. Nevertheless, there was again the tendency for performance to be somewhat worse for the fourth target, compared to the second and third target, $t\text{s} > 4$, $P\text{s} < 0.01$, but not compared to the first target, $t(11) = 1.4$, $P = 0.195$.

There was also again a weak indication that processing multiple targets eventually led to a deeper blink than when only a single target needed to be processed. Performance for the final target in the T1 D D T2 quadruplet of the 2-T condition was better than for the final target in the T1 T2 D T3 quadruplet of the 3-T condition (41 vs. 34%). As in Experiment 1, this difference failed to reach significance, $t(11) = 1.24$, $P = 0.24$. Taking the two experiments together, the effect approached significance, $t(22) = 1.97$, $P = 0.061$. We will return to this effect in Experiment 3, where we tried to push it a little further by presenting three instead of two initial targets.

As in Experiment 1, the T1 D T2 T3 quadruplet of the 3-T condition yielded a pattern remarkably different from the standard attentional blink found in the 2-T condition, as indicated by a number of targets (2-T vs. 3-T) × temporal position (1, 3, 4) interaction, $F(2, 22) = 8.42$, $MSe = 0.020$, $P < 0.01$. Pair-wise comparisons showed that accuracy was considerably improved for position 3 (68 vs. 41%), $t(11) = 4.37$, $P = 0.001$. Thus, as in Experiment 1, T3 was recovered, even though it fell well inside the period of an earlier-induced attentional blink. Similar relative improvements also occurred for T2 when presented immediately after T1, as can be seen from the increase in performance from temporal position 1 (69%) to position 2 (84%; averaged across the T1 T2 D D, T1 T2 D T3 and T1 T2 T3 T4 quadruplets) in Fig. 3, $t(11) = 4.66$, $P = 0.001$. In fact, performance for the second of two targets was, on average across the multi-target conditions, even better than performance for just a single target in the 1-T control condition, $t(11) = 2.34$, $P < 0.05$. Again, these patterns of results held regardless of whether or not performance was analyzed contingent upon T1 accuracy.

In all, the pattern was even clearer than in Experiment 1. More than two targets can be processed within an RSVP stream without much difficulty. Here up to four targets were detected without many problems. This goes against a T1-induced resource deficiency account, and provides evidence for the TLC account. Nevertheless, the fact that performance showed a small drop for T4, plus the hint that two initial targets induced a stronger blink than did one initial target suggests that limited target processing resources may still contribute to the attentional blink effect. The most remarkable finding was again that, once a blink had been induced, a target could escape from it when it was immediately preceded by another target, even when this preceding target itself could often not be reported. A similar benefit occurred at the start of the target stream (between the first and second target), when a blink had not been induced yet. This suggests that the control processes that operate during the blink, also operate outside the blink.

Experiment 3: independent effects of loss of control and limited capacity

Experiment 3 addressed several questions raised by the first two experiments. First, we were interested to see if the early recovery effect generalizes across and beyond the attentional blink period. For this purpose, an initial T1 was followed, after a variable number of distractors, by another triplet of targets (T2, T3 and T4). The number of temporal positions was increased from 4 to 11. On the basis of Experiments 1 and 2, we expected an attentional blink for T2 within these relatively late triplets, but a recovery for T3 and, to a lesser extent, T4.

Experiments 1 and 2 suggested that the attentional blink is caused by the first post-T1 distractor. However, it is the occurrence of T1 that somehow makes the first post-T1 distractor special (because no attentional blink occurs before T1). This raises the question as to which aspect of the appearance of T1 exactly sets the stage for the induction of a blink. Within TLC theory it has been proposed that the central executive is required for target identification and response planning and therefore unavailable for control of the input filter (Di Lollo et al., 2005). This would mean that executive control cannot be returned to the input filter as long as target processing has not finished. Elsewhere, however, it has been proposed that executive control is required to switch from rejecting the leading distractors in the stream to accepting the first target (Kawahara, Zuvic, Enns, & Di Lollo, 2003; Kawahara et al., 2005). This would mean that, in principle, executive control could be returned to the input filter as soon as the switch is complete, even when the target itself still needs processing. Another part of Experiment 3 provided a test between these two distinct possibilities. We employed a 4-T condition in which the crucial series of items now began with three successive targets (T1, T2, T3), which were followed by a fourth target (T4) after a variable number of distractors. Important here is the shape of the performance function for T4 after these early triplets. If target processing itself demands executive control (e.g., for identification and report), then we should find that the attentional blink is time-locked to the penultimate target (T3), since T3 is the last one to require the executive control. This means that a fully-fledged attentional blink for T4 should be induced, comparable to the one for T2 in the 2-T condition, but shifted backward in time by two temporal positions. In contrast, if it is only the switch from distractor to target processing that requires executive control, then we should find that the attentional blink for T4 is time-locked to T1's temporal position, since that is when the switch occurs. This would mean that by the time T4 appears, control over the input filter should at least be partly regained, and T4 should therefore suffer relatively less and recover early from the attentional blink compared to the 2-T condition.

However, and this is the third part of our exploration, Experiments 1 and 2 suggested that limited capacity resources may also affect the shape of the attentional blink function. There was a hint of performance for the last target being worse after two initial targets than after only one initial target. Experiment 3 may provide a stronger test, because in the 4-T condition performance for the last target was now measured after the processing of three, instead of two, early targets.

Method

Participants

Thirteen students of the Vrije Universiteit Amsterdam (five males; two left-handed; aged 18–29 years; average 21 years) participated in return for monetary payment.

Stimuli, procedure and design

The experiment was the same as Experiment 2, except for the following changes. The number of crucial temporal positions was increased to 11 (embedded in a stream of 23 items in total, with always at least one distractor at the end of the series). The 1-T and 3-T conditions were left out. In the 2-T condition, T1 was always presented at temporal position 1, whereas T2's temporal position varied between 2 and 11. In the 4-T condition, T1 was always presented at temporal position 1. In the early triplet version of this condition, T2 and T3 were presented immediately following T1, at positions 2 and 3. After a variable number of distractors (between 0 and 7), T4 then followed at either one of the positions 4–11. For example, a particular series of eleven might look like T1 T2 T3 D D D D T4 D D D. In the late triplet version of the 4-T condition, T1 was followed by a variable number of distractors (between 0 and 7), after which T2, T3 and T4 were presented successively. For example, a particular series might look like T1 D D D T2 T3 T4 D D D D. The T1 T2 T3 T4 D D D D D D D series applies to both versions. All trial types were randomly mixed within eight blocks of 75 trials each. In the end this resulted in 24 trials for each number of targets and combination of temporal positions. The experiment was preceded by 40 practice trials. The experiment lasted 1 h and 45 min.

Results

The data were treated as in the previous experiments, including the correction for guessing. Again, the overall pattern of results for post-T1 targets was independent of whether T1 identification was correct or not.

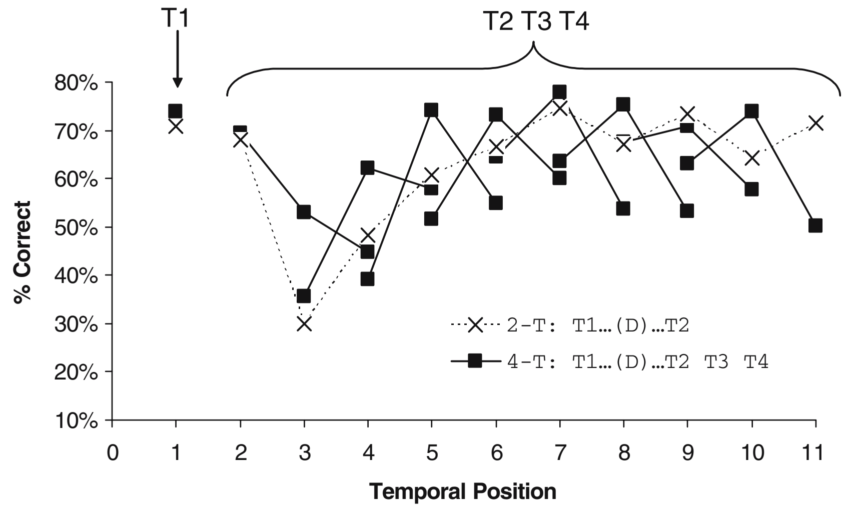

Fig. 4 Percentage correct scores for the two target (*2-T*) condition and the relatively late triplet versions of the four target (*4-T*) condition of Experiment 3, as a function of temporal position. Note that the eight possible triplets are represented by a set of three connected *square symbols*

The first question was whether the early recovery from the blink found for the fourth temporal position in Experiments 1 and 2 extended to the entire attentional blink period. For this purpose, Fig. 4 shows the real proportions correct target identification for T1, and for the relatively late triplets of T2, T3 and T4 in the 4-T condition, as a function of temporal position 1–11, compared to performance for T2 at the same temporal positions in the 2-T condition. Performance for T1 did not differ significantly for the two conditions (71 vs. 74%, $t(12) = -1.9$, ns). Detection accuracy for T2 in the 2-T condition revealed a classic attentional blink pattern: there was lag-1 sparing when T2 immediately followed T1 (at temporal position 2), followed by a steep drop in performance for temporal position 3, after which performance gradually improved again. The accuracy pattern for T2 in the T2 T3 T4 triplets of the 4-T condition was very similar: it also showed lag-1 sparing (at temporal position 2), and a subsequent drop in performance that tended to be slightly worse than in the 2-T condition, as indicated by a trend towards a main effect of the number of targets, $F(1, 12) = 3.69$, $MSe = 0.025$, $P = 0.079$, and a number of targets × temporal position interaction, $F(7, 84) = 1.97$, $MSe = 0.013$, $P = 0.069$. (Note that in the 4-T condition, T2 could not occupy the last two temporal positions, since these were reserved for T3 and T4; hence, the ANOVA was conducted with two levels for number of targets [2-T and 4-T] and eight levels for temporal position [2–7]). More importantly, performance for T3 in the T2 T3 T4 triplets of the 4-T condition improved relative to targets in the exact same temporal position in the 2-T condition; number of targets, $F(1, 12) = 5.11$, $MSe = 0.091$, $P < 0.05$; number of targets × temporal position interaction, $F(7, 84) = 2.49$, $MSe = 0.016$, $P < 0.05$. The interaction reflects the fact that improvements were relatively small at later temporal positions, possibly due to a ceiling effect. In contrast, performance for T4 was considerably worse than could be expected on the basis of the 2-T condition, number of targets, $F(1, 12) = 6.04$, $MSe = 0.118$, $P < 0.05$. This was especially the case later in the stream; number of targets × temporal position interaction, $F(7, 84) = 2.25$, $MSe = 0.014$, $P < 0.05$. Why no recovery occurred for T4 remains an open question. One reason may be that, by the time T4 appeared, observers were running out of STM capacity. However, performance for T4 was quite good in Experiments 1 and 2. Perhaps capacity limitations are less detrimental when all targets are presented in immediate succession, possibly allowing for more efficient rehearsal or other memory processes. A second reason may lie in the fact that here the main conditions (2-T and 4-T) were mixed, whereas previously they were blocked. This may have meant that on some 4-T trials, participants first detected T1, then missed T2, then detected a recovered T3, after which they decided it must have been a 2-T trial and did not bother to look for or report T4.

The second question was whether the attentional blink is related to the switch from distractor to target category, or to the necessity to process and identify a target.

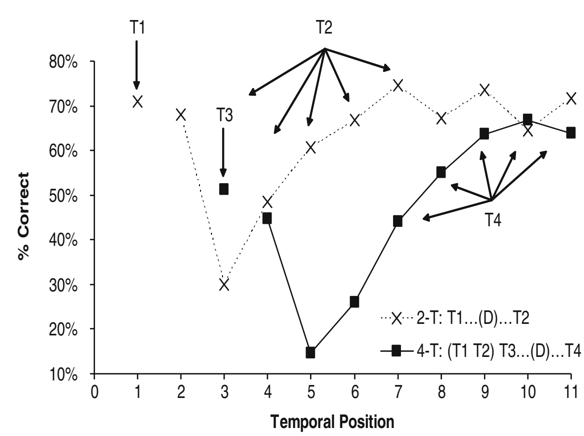

Fig. 5 Percentage correct scores for the penultimate and final targets in the two-target (2-T; i.e., *T1* and *T2*) condition and the relatively early triplet versions of the four-target (4-T; i.e. *T3* and *T4*) condition of Experiment 3, as a function of temporal position

For this purpose we considered performance for the final target (T4) in the 4-T condition after relatively early triplets of T1, T2 and T3, and compared it to performance for the final target (T2) in the 2-T condition, after only a single T1. If the blink is related to a category switch, then performance should be time-locked to T1. If the blink is related to target processing itself, then performance should be time-locked to the penultimate target, and we should see it being shifted backward in time in the 4-T condition. Figure 5 plots the detection accuracy for the penultimate and final targets in the 2-T and 4-T conditions, that is, for T1 and T2 in the 2-T condition, T3 and T4 in the 4-T condition. From the graph it is clear that in the 4-T condition, a full attentional blink is induced after T3, with a pattern very much comparable to the one induced by T1 in the 2-T condition, but shifted backward in time by two temporal positions. The only difference is that performance is overall worse in the 4-T condition, a finding we will return to in the next paragraph. We conclude that the attentional blink is time-locked to the penultimate target (and, logically, to the first post-T1 distractor). This means that the attentional blink is not due to the requirement to switch from the distractor to the target category. Instead, it only appears to occur after the penultimate target has been processed.

The final question we were trying to answer was whether there was any remaining role for limited capacity resources in causing the blink. For this purpose we again compared final-target (i.e. T4) performance for the early triplet trials of the 4-T condition to that for the final target (i.e. T2) of the 2-T condition. The idea is that having to process three early targets (T1 T2 T3) will lead to a stronger reduction in resources than having to process a single T1. Figure 6 shows the same data as Fig. 5, but for the purpose of comparison the curve for the 4-T condition has been shifted forward by two temporal positions, so that it aligns with the curve for the 2-T condition. As noted in the previous paragraph, the two curves are highly similar, except that overall performance was worse in the 4-T condition. This was confirmed in an ANOVA with number of targets (2-T vs. 4-T) and temporal position (2–9) as factors, which showed a main effect of number of targets, $F(1, 12)=25.78$, $MSe=0.038$, $P<0.001$ (as well as a main effect of temporal position, $F(7, 84)=29.98$, $MSe=0.024$, $P<0.001$). However, the interaction was also significant, $F(7, 84)=2.90$, $MSe=0.012$, $P<0.01$. Closer inspection revealed that the interaction was mainly caused at the tail of the curves, where there was an unexpected drop in performance for temporal position 8 in the 2-T condition. Note that this position fell outside what appeared to be the crucial attentional blink period in our experiment, which seemed to be over by temporal position 7, the time by which performance was back on the level of T1 (or T3 in the 4-T condition). We therefore re-analyzed the data again for temporal positions 2–7. There was again a main effect of number of targets, $F(1, 12)=31.23$, $MSe=0.035$, $P<0.001$, of temporal position, $F(5, 60)=29.00$, $MSe=0.026$, $P<0.001$, but now no interaction, $F<1.3$, $P=0.280$.

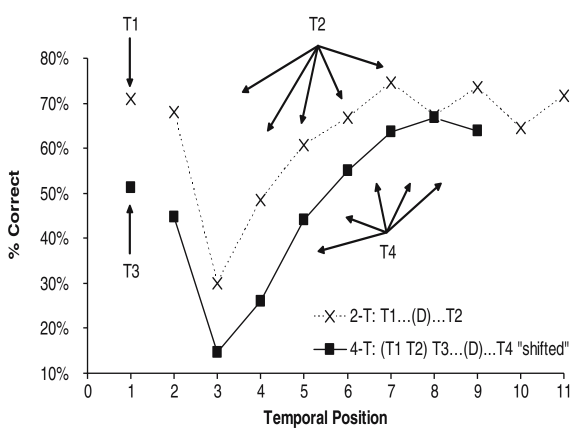

Fig. 6 Percentage correct scores for the penultimate and final targets in the two-target (2-T; i.e., *T1* and *T2*) condition and the relatively early triplet versions of the four-target (4-T; i.e. *T3* and *T4*) condition of Experiment 3, as a function of temporal position. Note that the data are the same as in Fig. 5, but that the curve for the 4-T condition has been shifted forward in time by two temporal positions, to allow a direct comparison with the 2-T condition

We conclude that limited capacity resources on the one hand, and whatever causes the attentional blink on the other, are largely independent factors, leading to mainly additive effects on performance. In other words, limited capacity target processing resources do not significantly contribute to, or cause the blink, but affect overall performance.

General discussion

The present work has revealed four main findings with regard to the attentional blink. First, in Experiments 1 and 2 the lag-1 sparing effect for a second target spread to a third and even a fourth target at lags 2 and 3, as long as the targets were presented in immediate succession. This result replicates and extends earlier findings by Di Lollo et al. (2005; Kawahara et al., 2005) and goes against a T1-induced lack of resources as an explanation for the attentional blink (viz. Chun & Potter, 1995; Jolicoeur & Dell'Acqua, 1998; Shapiro, Arnell, & Raymond, 1997). Instead, the blink appears to be induced by the first post-T1 distractor, pointing towards the importance of input control processes. Second, even when an attentional blink proper had been induced, targets recovered early from it when preceded by another target. This finding occurred across the entire time course of the attentional blink. In fact, improvements even occurred before an attentional blink was induced, namely for T2 when it immediately followed T1. Third, the attentional blink was not time-locked to the switch from the distractor category to the target category when T1 was presented, but instead to the penultimate target and thus also to the first post-T1 distractor. The fourth finding of importance was that target processing requires limited capacity resources, but that this is not the major cause of the attentional blink. Performance may suffer overall when multiple targets need to be remembered, but this does not alter the relative depth or duration of the attentional blink. Limited-capacity resources contribute to performance independently of whatever causes the attentional blink.

Of all existing theories, the TLC account appears most consistent with the results. The TLC explanation states that target processing requires the allocation of central executive control functions. This means that this control is no longer available to govern the input side of the process, causing the system to become vulnerable to incoming stimuli. As long as these are targets there are few problems, but an incoming distractor may exogenously reset the input filter, causing subsequent targets to be ignored or overwritten. Although the executive control function itself may be seen as a limited-capacity mechanism, the capacity limit does not apply to target processing per se, but to the number of tasks (or task aspects) that can be handled at a time.

Of course, ultimately there is likely to be a limit to the number of targets that can be processed, also within TLC, but this limit will operate independently of the attentional blink. This was confirmed in the present study. Here the limit appeared to be around four items. Probably not coincidentally, four has also been believed to be the approximate limit of STM (see Cowan, 2000, for a review). This implies that STM capacity is a factor that plays a role only after targets have been successfully selected from the RSVP stream, contrary to some of the existing attentional blink theories, which assign a pivotal role to STM in causing the blink (Chun & Potter, 1995; Jolicoeur & Dell'Acqua, 1998; Shapiro et al., 1997). In further support of this, Akyürek and Hommel (2005) showed that when observers were given a STM task in addition to the RSVP task, target detection deteriorated with increasing memory load. However, this was an overall effect across the RSVP stream; memory load did not interact with lag.

Intact input filter?

Although we believe that, generally speaking, the TLC account fits our data well, in some respects the fit is less comfortable. For instance, to be able to explain how targets can recover early from the blink when preceded by another target, the TLC account would have to propose that the incoming targets either result in a reinstatement of executive control over the input, or lead to an exogenous reset of the input filter so that the earlier disturbance caused by the post-T1 distractor is reversed. The first option would be inconsistent with the theory's assumption that the attentional blink is due to the unavailability of executive control over the input filter. The second option is also inconsistent, now with the idea of an exogenous disturbance of the input filter. If we assume that the first post-T1 distractor has disturbed the input filter to the extent that it no longer effectively distinguished targets and distractors, then what is the mechanism by which a target can exogenously reinstate this filter? For that it seems that the item should at least be recognized as being a target, but how is this status being determined without an input filter in the first place? Somehow the filter must still be intact.

Keeping the filter intact while processing the first target would make functional sense, because internal mental processes need to be protected against interference from the outside world. If targets and distractors themselves would be able to exogenously determine whether they will be processed or not, then this would leave the observer completely at the mercy of the incoming stimuli whenever his or her central executive is occupied with a different task. Of course, some stimuli may possess this capability of resetting the system, but if so, they are likely to be much more distinguishable than the targets and distractors used in typical RSVP tasks (e.g., Yantis & Jonides, 1984; Theeuwes, 1992).

Support for an intact input filter also comes from work by Nieuwenstein, Chun, Hooge, and Van der Lubbe (2005). In the standard version of their RSVP task, T1 and T2 were two red digits, embedded in a stream of black letter distractors. In the crucial condition, however, T2 was preceded by a red rather than a black distractor letter. The result was that T2 detection improved considerably relative to the standard condition. Nieuwenstein et al. argued that the attentional blink is caused by a delayed engagement of attention onto T2, which makes it vulnerable to masking. By precueing T2 with a similar distractor, the engagement is speeded, leading to better detection. Similar pre-cueing effects have been found on a semantic level, such that T2 performance improves whenever T1 or one of the intervening distractors is of the same semantic category (Maki, Frigen, & Paulson, 1997; Martens, Wolters, & Van Raamsdonk, 2002; Potter, Dell'Acqua, Pesciarelli, Job, & Peressotti, 2005). The reverse also appears to occur: at least for short lags, a semantic relationship with T2 also improves T1 detection (Maki et al., 1997; Potter et al., 2005). This latter result suggests that, at least at very short lags, T1 and T2 may still be in some form of competition for shared resources (see Potter et al., 2002).

In this respect it is interesting to see to what extent, in the present experiments, performance on a particular target was affected by whether the immediately preceding target was correctly identified or not. If two successive targets stand in direct competition for the same resources, then one might expect a trade-off: performance might suffer if the preceding target is correctly identified. To maximize power we collapsed all pairs of successive targets across all lags and experiments and assessed performance of the second of the two depending on whether the first was identified correctly or not. It turned out that, on average, identification of the second target was 73% when the preceding target was identified, and 78% when the preceding target was not identified, a difference that was significant, $t(36) = 2.51$, $P < 0.02$. This suggests that in the present experiments too, targets not only prime each other (so that the second of the pair benefits), but at the same time also stand in some competition with each other.

Note, however, that most of these cueing, priming and competition effects (except the reverse T2–T1 priming found by, e.g., Potter et al., 2005) occurred across T1–T2 lag, casting doubt on whether they are directly related to the attentional blink itself. In our experiments, benefits from a preceding target occurred not only inside, but also outside the attentional blink period. Taken together, then, these findings suggest that an input filter (whether looking for visual or semantic information) remains rather intact across the entire range of temporal positions.

An alternative account: the overinvestment hypothesis

We would like to propose an alternative possibility that borrows heavily from the TLC account, but gives a different twist to it. It also merges with the overinvestment hypothesis as offered by Olivers and Nieuwenhuis (2005b). The idea is that the attentional blink is the result not of a TLC, but, on the contrary, of the overzealous application of control over the input. Overall, observers invest too much in the RSVP task. Following earlier proposals (Raymond et al., 1992; Visser, Bischof, & DiLollo, 1999a; Di Lollo et al., 2005) we suggest that observers employ an attentional set for targets, and against distractors. Such an attentional set may be seen as a template or input filter, and contingent upon it, target properties are automatically enhanced, whereas distractor properties are rejected. The problem is that in many RSVP tasks the targets and distractors cannot be unambiguously distinguished. This means that once the RSVP stream starts, and before T1 has occurred, the attentional set is in conflict: if it is too strongly set for target properties, then the higher target processing systems may be spuriously triggered by distractors resembling a target (Visser, Bischof, & Di Lollo, 2004). However, if the observer is trying to keep things under control and is too strongly set against selecting distractors, some targets may actually be missed if they do not carry sufficient evidence for being a target. Note that both possibilities may lead to an overall reduction in performance even for T1. We further assume that whenever a target is selected, the control over the input loosens. Importantly, we think that this is not because there is a loss of control, but because the incoming perceptual evidence suggests there is relevant information in the stream (with relevance being determined by the attentional set). Metaphorically speaking, the attentional gate opens. Similarly, we assume that when a distractor is accidentally selected, this will (again contingent upon the attentional set) automatically lead to a temporary tightening of the input control; that is, the bias against selection of items from the stream will be enhanced and the attentional gate closes. These effects occur across the entire stream, regardless of temporal position and regardless of whether an attentional blink has been induced. The attentional blink is then explained as follows: T1 leads to a further opening of the attentional gate, allowing the first post-T1 distractor to enter. Even though this distractor in itself is not that harmful for identification of T1, contingent upon the attentional set, the system overly corrects for the erroneous selection and temporarily closes the gate for further processing, leading to an attentional blink. However, the attentional set is still in place, and given sufficient evidence for a target, it may reopen the gate. Such sufficient evidence may be present when two targets immediately follow each other, leading to a recovery from the blink for the second of the two. It may also be provided by a preceding distractor if the distractor is sufficiently similar to the target (Nieuwenstein et al. 2005). In any case, we see the attentional blink as merely a special case of the selection process that is going on during the entire stream, namely the active monitoring for targets while attempting to reject distractors.

The idea shares with the TLC account that the input filter is changed dynamically and automatically by incoming stimuli. The difference is that we propose that these incoming stimuli lead to a temporary tightening of control rather than to a loss of control. On face value, the idea is similar to one of the very first explanations of the attentional blink. Raymond et al. (1992) proposed that T1 needs to be protected against interference from subsequent distractors and hence the post-T1 items are inhibited, often including T2. Note, however, that this account would predict that immediate post-T1 targets are also inhibited, which goes against the present results. The difference is that we do not propose that T1 needs protecting. The suppression of the input is not triggered by T1, but by the first post-T1 distractor.

The idea of an overzealously applied attentional set also explains why performance may actually improve when the observer is in a more diffuse attentional state (Olivers & Nieuwenhuis, 2005a, b). When distracted by other thoughts, other tasks, or other stimuli, control settings for the RSVP stream may be less tight. This would mean that (1) distractors are less likely to spuriously trigger target processing mechanisms (because they are less likely to match the target set), and (2) whenever a distractor is accidentally selected, it is less likely to lead to a strong reactive suppression of the stream. Together, this should lead to improved performance for T1 as well as T2, as was found by Olivers and Nieuwenhuis. The prediction would be though that a reduction of the amount of attention invested is only beneficial if targets and distractors can be relatively easily distinguished without the necessity for a too strongly specified attentional set (such as the digits and letters used by Olivers and Nieuwenhuis). If targets and distractors are too similar, a lack of attention may actually prove to be detrimental.

Other effects may be explained as well. The effects of target–distractor similarity could be accounted for by assuming that a distractor that is similar to the target is more likely to be selected and thus trigger the overzealous control system. Furthermore, evidence suggesting that enhanced or prolonged T1 processing correlates with reduced T2 detection (see e.g., Fig. 6 of Seiffert & DiLollo, 1997) may be reinterpreted as actually reflecting enhanced (or increased probability of) selection of the post-T1 distractor, resulting in stronger suppression of subsequent items. Interestingly, Nieuwenhuis, Gilzenrat, Holmes, and Cohen (2005) have recently proposed that the attentional blink is related to the phasic response of the locus coeruleus (LC), a nucleus in the brain stem largely responsible for the noradrenergic innervation of the cortex. The LC is highly sensitive to the behavioral relevance of stimuli, and its activity may well reflect or cause the initial enhancement and subsequent suppression of the input. In any case, we have no doubt that future research will reveal some exciting new insights in the attentional blink phenomenon.

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